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Radiation effects on ALICE V0 detector components

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Abstract

The 60 MeV proton beam delivered by the RADEF facility of the University of Jyväskylä (Finland) was used to measure the radiation effects on the counter components of the V0 detector of ALICE. There are the scintillator BC404, the wavelength shifting fibres BCF9929A and the optical fibres BCF98 from Bicron (Saint-Gobain). The light yield and the time resolution given by a counter of the inner ring of the V0C array, mounted within a dedicated device, were measured as a function of the radiation dose up to about 300 krad. A global light attenuation of the order of 30% can be anticipated during 10 years of ALICE running.

Key words: ALICE, V0 detector, Radiation tolerance, BC404, BCF9929A, BCF98
PACS: 29.40.Mc, 61.82.-d, 25.40.-h

1 Introduction

The detailed description and physics motivation of the V0 detector of ALICE can be found in [1]. It is a small-angle detector consisting of two arrays of 32 scintillator counters (named V0A and V0C) installed on both sides of the ALICE collision vertex. The counters cover the pseudo-rapidity ranges of $2.8 < \eta < 5.1$ (V0A) and $-3.7 < \eta < -1.7$ (V0C).

The V0C array is shown in Fig. 1(left). It is a disk of eight sectors of six elements, one for rings 1 and 2, two for rings 3 and 4. The light produced by the two elements of rings 3 and 4 is collected by a single photo-multiplier. The

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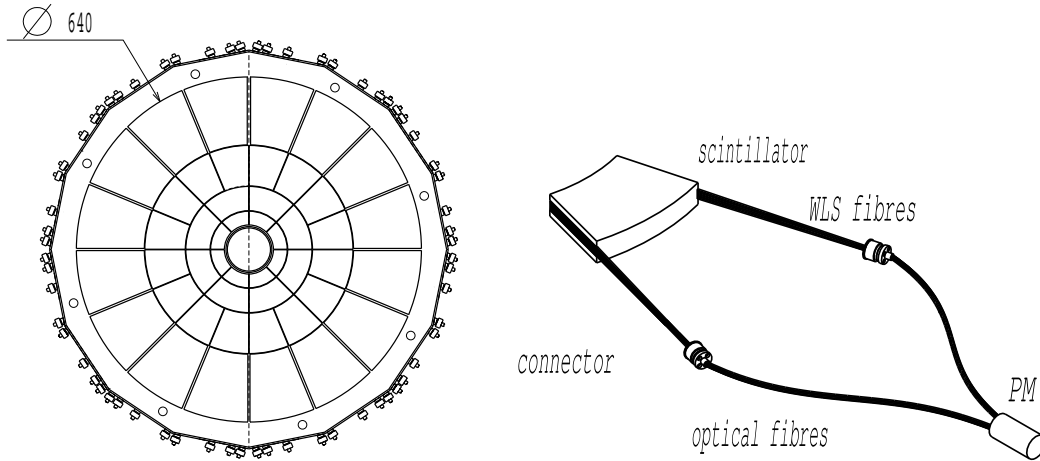


Fig. 1. Front view (left) and elementary counter of the V0C array.

individual counter is made of two layers of 9 Wavelength Shifting Fibres (WLS) glued along the two radial edges of a scintillating piece and connected to two bundles of 9 optical fibres as shown in Fig. 1(right). The components [2] used are a BC404 scintillator 2 cm thick, BCF9929A WLS fibres (double cladding) of 1 mm in diameter and BCF98 optical fibres (d.c.) of 1.1 mm in diameter.

Amongst all the questions raised during the V0 development, there was the problem of radiations and their effects on the signal delivered by each channel of the detector. In order to get quantitative answers to these questions, we carried out measurements with a 60 MeV proton beam delivered by the Jyväskylä RADEF facility bombarding a counter identical to the one of the ring 1, the most exposed to radiations.

2 The radiation effects in V0 scintillating materials

The choice of the elements listed above (scintillating plastic and WLS fibres) was mainly dictated by the time resolution performance of the counter for the detection of one MIP (Minimum Ionizing Particle). Their hardness to radiations was not a decisive criterion. The radiation doses through the V0C array estimated during 10 years of operation are of the order of 300, 50, 20, and 10 krad for the elements of rings 1 to 4 respectively [3]. A few tests of light production degradation under radiations can be found in the literature for several types of scintillating plastics, WLS and optical fibres.

The BC404 scintillator (decay time, 2 ns; peak emission, 408 nm; attenuation length, 1.7 m) was tested in radiation conditions up to 3 Mrad [4]. A light reduction of about 5% was measured for a dose of 200-300 krad from a Cs^{137} radioactive source. As a consequence, the degradation of the BC404 signal (factor of reduction **a**) does not seem to be a major problem for the ALICE

experiment, even for the most exposed elements of the V0C array.

According to published measurements on WLS fibres [5], more drastic is the effect of radiation on the light emitted by the WLS fibres. Unfortunately, no data exist for the fibres used for the V0 detector. Two effects must be considered here. The first one (factor of reduction **b**) is the brightness/transparency deterioration localized in the part of the fibres where the wavelength shift takes place. The absorbed doses are similar to the ones experienced by the scintillating plastic, namely the ones given above for each ring of the array. The second effect is the reduction of the mean path of the photons (factor of reduction **c**) in the part of the fibres exposed to radiations between the scintillating plastic and the connector. We evaluate these radiation doses to be 50, 20, 10, and 6 krad at the external radius of each associated ring, then decreasing very rapidly [3]. For the fibres of ring 1 counters, the dose is only 30 krad at 10 cm. The resulting radiation effect on the WLS fibres will be the loss of brightness added to the loss of transparency.

The optical fibres are exposed to radiations too (factor of reduction **d**). The dose can be very approximately evaluated starting from the results shown in [3]. At 32 cm from the center of the V0C disk, the dose is about 3 krad for 10 years of data taking. A measurement with a 5 meter long multi-clad fibre [6] shows that the absorption of a 500 nm wavelength light is about 15% for the dose above.

Specific measurements seem to be useful to evaluate the effect of irradiation in the ALICE environment. The results presented below give a more precise knowledge of radiation effects on the actual V0 detector elements. The management of the detector along the time (10 years of LHC beam is the basic period to be considered) can thus be refined.

3 Setup of the irradiated scintillating device

We measured the evolution of the signal given by a counter of the ring 1 as a function of the radiation dose received by the scintillator alone (**a**), the WLS fibre coupled to the scintillator with optical cement (**b**), the WLS (**c**) and optical (**d**) fibres in their part used for the transport of the light. **a**, **b**, **c** and **d** are the fractions of initial light surviving after an irradiation of the counter (see Section 2).

A sketch of the device is shown in Fig. 2. The ring 1 element was coupled to four layers of nine WLS fibres (50 cm long) glued along its two radial edges. An aluminium plate of 2 cm in thickness set in front of the counter was used to define an area of radiation exposure ($2 \times 3 \text{ cm}^2$). One photo-

multiplier was connected to each WLS fibre bundle directly or through 50 cm long clear fibre bundle. PMT1, PMT2, PMT3 and PMT4 were used to measure the output signal affected by radiations. They measured respectively the light yield distributions **a**, **ab**, **ac** and **abd** after each stage of irradiation (Fig. 2).

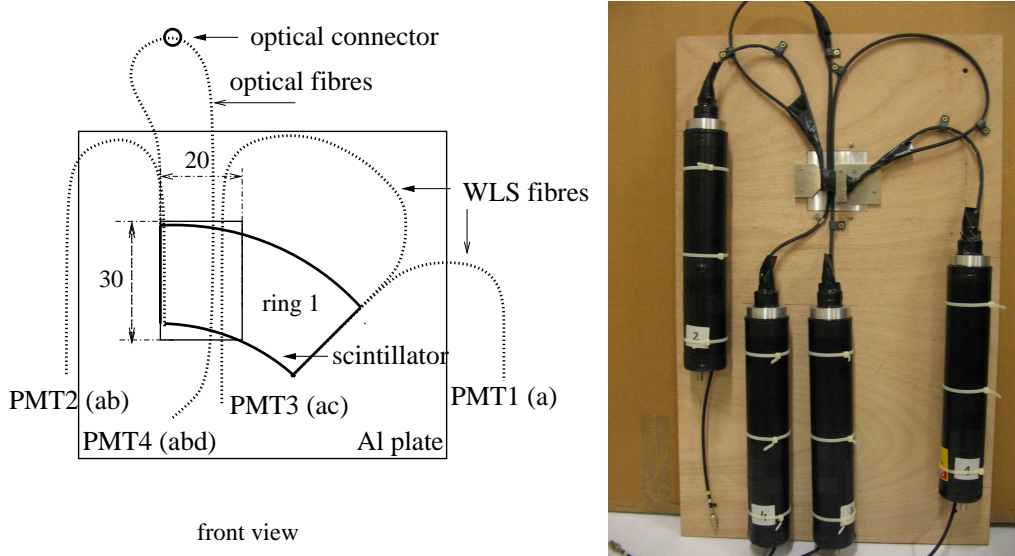


Fig. 2. Front sketch (left) and picture (right) of the irradiated counter.

4 Light measurements

We used a 60 MeV proton beam uniformly distributed within the window mentioned above. The beam had a cylindrical envelope, meaning that each proton trajectory was perpendicular to the counter entrance face. For a current of 1 nA in the accelerator ($6.25 \cdot 10^9$ p.sec⁻¹), the percentage of protons per cm² within the collimator was evaluated to be about 1.3%. It corresponded to $81.25 \cdot 10^6$ p.sec⁻¹.cm⁻². The initial signal, before any radiation effect, simulated about 7 MIPs as expected in ALICE.

After each exposure corresponding to a certain time of irradiation not longer than 45 minutes (time needed for a 100 krad dose), we measured, during about 15 minutes, the change of the setup included, the PMT signals provided by protons crossing the counter. Therefore, one measurement consisted of one irradiation followed by one signal measurement. This procedure lead to have two setups (Fig. 3), the first one for the irradiation of the counter installed directly in the beam at the end of the beam pipe, the second one for the signal measurements themselves. For this step, the beam intensity was decreased to a few 10^5 p.sec⁻¹ so that T1 and T2 PMTs used to provide the trigger could count the number of impacts. Several secondary signals were detected to control the radiation dose injected in the counter, and the beam intensity

during the signal measurements: X-ray counting rate from an Ag foil by a NaI detector, scattered protons by the same Ag target, direct protons by the trigger detectors and Faraday cups inside the vacuum chamber of the beam and at the end of the test bench. The complete measurement took about 14 hours.

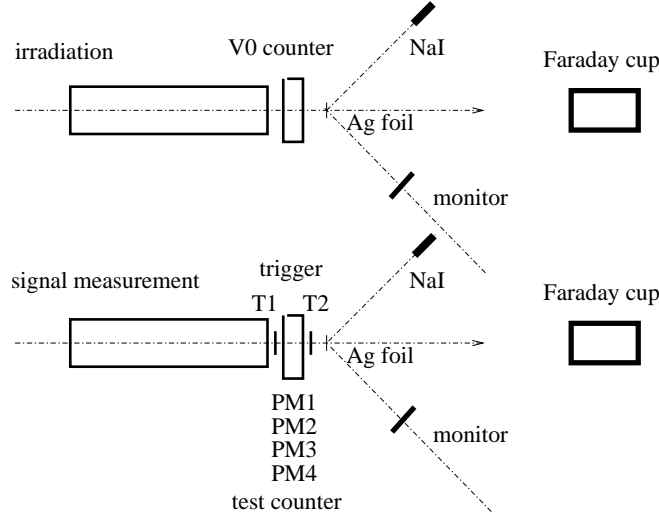


Fig. 3. Setups for irradiation (top) and light measurements (bottom).

5 Results

The dose injected in a scintillator by one proton per cm^2 can be written as follows:

$$\Delta E \times 100 / (1.02 \times 10^{-3} \times T \times 6.24 \times 10^{12}) = 1.57 \times 10^{-8} (\Delta E / T) \text{ rad}$$

where ΔE is the energy loss in MeV, T the thickness in cm and 1.02×10^{-3} the mass in kg per cm^3 of the scintillating element.

The value of the ratio $(\Delta E/T)$ depends on the irradiated zone of the counter. The figure 4 shows a cut view of the counter giving the size of the several components along the beam direction.

The $\Delta E/T$ ratio is constant for LHC energies ($2 \text{ MeV} \cdot \text{cm}^{-1}$), while it depends on the part of the counter for 60 MeV protons. The value of $\Delta E/T$ is given in Table 1 for each zone (Fig. 4) for which the residual light percentages after irradiation are called **a**, **b**, **c** and **d**. It means that in the present tests, for a 13.5 krad dose injected in the scintillator, 14.5, 11.7, 10 and 10 krad are respectively injected in the WLS fibres/cement volumes in the back and

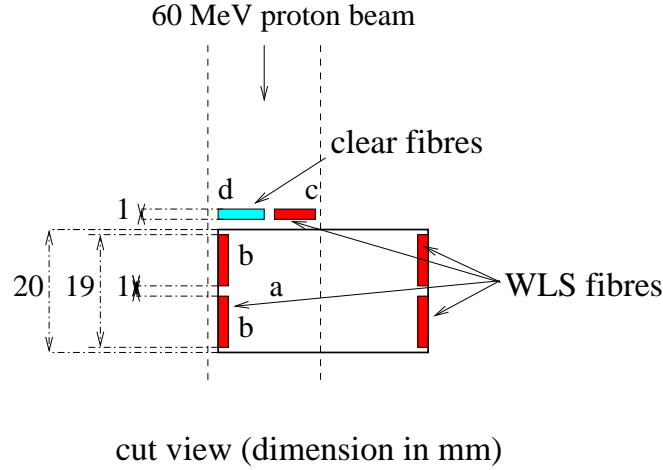


Fig. 4. Cut view of the counter under test.

front parts of the scintillator, in WLS and optical fibres passing in the beam envelope inside the collimator.

Irradiated zone (survival light (%))	$\Delta E/T$ (MeV.cm ⁻¹)	
	LHC energies	60 MeV protons
scintillator (a)	2	13.5
WLS/cement (b), back part of the counter	2	14.5
WLS/cement (b), front part of the counter	2	11.7
WLS fibres in transmission (c)	2	10.0
optical fibres in transmission (d)	2	10.0

Table 1

Values of the $\Delta E/T$ factor.

The results of the light measurements are given in Fig. 5. The light yield distributions are normalized on the initial measurements (before irradiation). The relative uncertainties are evaluated to about 3%.

The distribution (1) is the light given by the scintillator as a function of the injected dose. The distribution is confined within the range 0.95-1.05, showing no perceptible effect up to 300 krad, except a possible beginning of degradation starting at this dose. This observation leads to conclude that the scintillator used for the V0 detector is not intrinsically subject to significant degradation for the expected dose of 200-300 krad. We thus can give the value 1 to **a**. This factor thus disappears from the other measured light yield distributions below.

The distribution (3) is the light from (1) going through the irradiated 3 cm long segment of the WLS fibres. This distribution gives the function of transmission

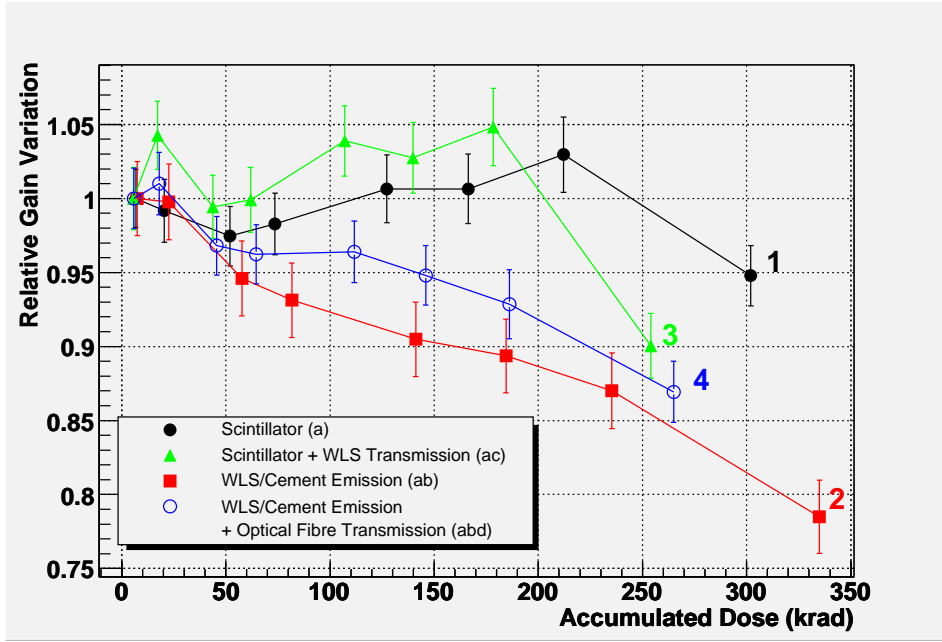


Fig. 5. Relative light distributions as a function of the radiation dose injected inside several zone/elements constituting a V0C counter.

c due to the irradiated WLS fibres. We measured no effect for a dose up to 150 krad and a clear attenuation from a dose of 200-250 krad. In the ALICE running conditions, the maximum dose expected during 10 years of exposure is not more than 30 krad close to the scintillating block and 3 krad at the level of the connector, with a mean value of 15 krad along the fibre of 30 cm in length. That corresponds to about 150 krad injected in a 3 cm length of fibre. That means the 250 krad dose of the test is larger than the expected dose in ALICE. We can thus deduce that no significant loss of light coming from irradiation of WLS fibres alone is expected.

The distribution of light (2), namely the light from the WLS/cement volume close to the back face of the counter (**b**) as a function of the dose, is decreasing continuously from the initial value 1 to less than 0.8 at 350 krad. The production of light from WLS fibres embedded in optical cement is the most affected element of the V0C counter. 20% of light attenuation has to be anticipated during the life time of ALICE for which a dose of 200-300 krad is foreseen.

Finally, the distribution (4), plotted as a function of the dose injected in the WLS/cement volume close to the front face of the counter, shows the light emitted from the volume above (**b**) passing through an irradiated 3 cm long segment of the optical fibres. This distribution is given by the product **bd**. Any effect of radiation on optical fibre transmission should be reflected by a distribution (4) with a slope different from the one of the distribution (2). No such an observation is shown by the results. The optical fibre will thus be not greatly degraded during the ALICE experiment. Moreover, the radiation dose

anticipated in the optical fibres (a few krad) is extremely low as compared to the one injected in this test.

As a conclusion, and taking into account the incertainties of the measurements, we can expect a light attenuation due to radiation effects of about 25-30%. The major part of this degradation originates from the loss of brightness by the WLS fibre/cement assembly ($\mathbf{b} = 20\%$). Several reasons can explain this observation. The fraction of fluorescent materials is damaged, changing the ability for fibre to re-emit light. The emission spectrum is changed [5], deteriorating the matching with the wavelength range acceptance of the PMT. No quantitative evaluation of this two individual effects has been carried out. Only the combined effect could be measured. The residual contribution ($\mathbf{a} + \mathbf{c} + \mathbf{d} = 5\text{-}10\%$) comes from secondary effects on the scintillator, and on the light transmission by the WLS/optical fibres used as light guides to the photo-multipliers. Moreover, a recovering of the scintillation cannot be significant during the total time of the measurements (14 hours). That means that the 25-30% effect should be considered as a maximum.

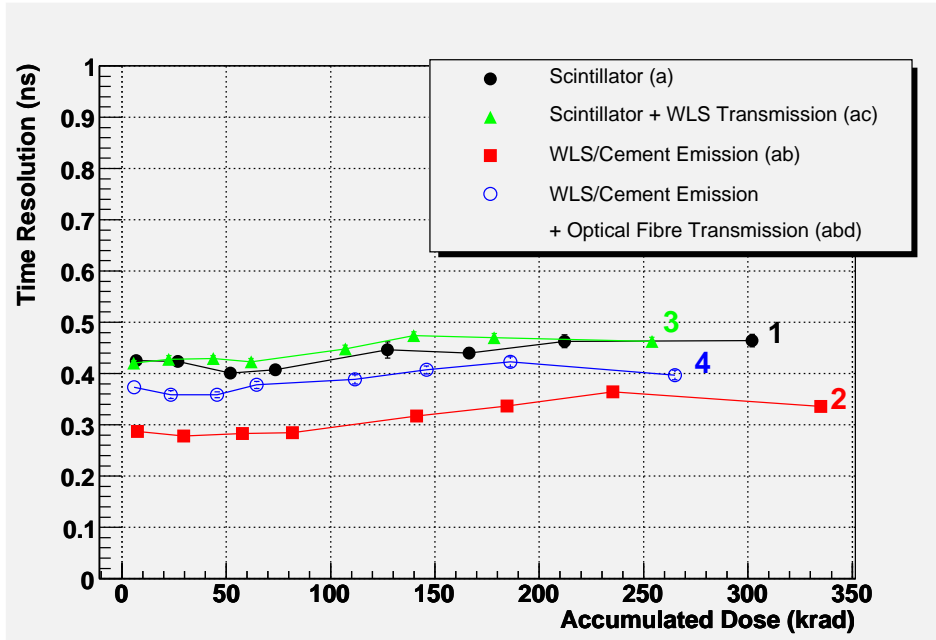


Fig. 6. Time resolution distributions as a function of the radiation dose injected inside several zone/elements constituting a V0C counter.

The time distributions are extracted from the measurement of the time differences between the T1/T2 trigger (start signal) and the PM1, PM2, PM3 and PM4 measuring the output signals from the V0 sample (stop signal). The time resolution distributions (σ_{time}) given by PM1, ..., PM4 alone are plotted as a function of the radiation dose in Fig. 6. The values mainly depend on the photo-multiplier used on each channel. They are all confined in the range 300-500 ps. A weak dependence of this parameter with the radiation dose is measured, namely less than 100 ps between 0 and 300 krad. It can be thus

seen that the time resolution increases when the light yield decreases as it is expected in such a situation. It has to be recalled that the detected charges are large in the present test. They correspond to 7 MIPs in the ALICE conditions. $1/\sqrt{(N_{p.e.})}$ gives the dependance of the time resolution with the number of produced photo-electrons [1]. The time resolution will thus be larger for the MIP in the ALICE conditions (about 600-700 ps). As a consequence, the absolute degradation of this parameter will be much more important when the radiation dose increases.

6 Conclusion

A control of radiation effects on the components of the ALICE V0 detector was carried out with a proton beam of 60 MeV delivered by the Jyväskylä RADEF facility. These components are the scintillator BC404, wavelength shifting fibres BCF9929A and optical fibres BCF98 from Saint-Gobain.

It was observed that a moderate light attenuation can be expected during the 10 years of the ALICE experiment. A global reduction of the order of 25-30% was measured for a dose of about 300 krad. This light degradation is mainly due to radiation effects on the light emission by WLS fibres embedded in optical cement. The light provided by the scintillating material and the light transmitted by WLS and optical fibres are not significantly lowered. A possible compensation of this loss of signal can be envisaged through a gain adjustment of the photo-multipliers. Moreover, the construction of spare rings 1 and 2, the rings the most exposed to radiations, will allow to secure the permanent utilization of the V0 detector in ALICE.

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